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BLAST LOAD GENERATOR FACILITIES AND INVESTIGATIONS OF DYNAMICALLY LOADED CONCRETE SLABS

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FOREWORD

This paper was presented by Mr. W. J. Flathau, Chief, Protective Structures Branch, Nuclear Weapons Effects Division, at the New York Academy of Sciences international conference on "Prevention of and Protection Against Accidental Explosions of Munitions, Fuels, and Other Hazardous Mixtures" held in New York City 10-13 October 1966.

Mr. G. L. Arbuthnot was Chief of the Nuclear Weapons Effects Division, Mr. J. B. Tiffany was Technical Director, and Col. John R. Oswalt, Jr., CE, was Director of the Waterways Experiment Station at the time of preparation and presentation of this paper.

38-344

BLAST LOAD GENERATOR FACILITIES AND INVESTIGATIONS OF DYNAMICALLY LOADED CONCRETE SLABS*

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Introduction

Due to the complicated nature of many of the problems associated with weapons effects and to the moratorium on full-scale nuclear weapon tests, it was necessary to develop other means of obtaining needed experimental data; hence, laboratory facilities were developed to simulate the various effects associated with the detonation of a nuclear device. After a considerable amount of planning and effort, one such laboratory facility, the Blast Load Generator, was developed at the U. S. Army Engineer Waterways Experiment Station (WES). Recently the Blast Load Generator facility has been used to investigate the response of reinforced concrete slabs subjected to airblast loading.

Experimental Facilities

Large Blast Load Generator

The Large Blast Load Generator (LBLG)[1] is a three-dimensional device designed primarily to test underground protective structures

* The experimental investigation was conducted at the U. S. Army Engineer Waterways Experiment Station under the sponsorship of the Office, Chief of Engineers in cooperation with the Office of Civil Defense.

subjected to pressures simulating those generated by both kiloton and megaton nuclear devices. Pressures from 5 to about 400 psi having rise times of approximately 2 to 4 msec and duration times up to several seconds can be reproduced in the LBLG.

The LBLG (Figure 1) has two basic components, the central firing station and the test chambers. The central firing station is a massive, posttensioned, prestressed-concrete reaction structure designed to resist the dynamic or static loads generated in the test chamber. There are two test chambers, cylindrical steel bins 23 ft in diameter, that contain the test media and test structures. The chambers (Figure 1) are formed by stacking three steel rings, adding a ring that contains firing tubes, and adding a top lid that is called the bonnet. High explosives placed in the firing tubes are detonated to produce the overpressure in the test chamber.

Small Blast Load Generator

The Small Blast Load Generator (SBLG) can contain static pressures to 500 psi and produce dynamic pressures to 250 psi having a minimum rise time of several milliseconds and durations greater than one second. The generator (Figure 2) has a 9/16-in.-thick-steel cylindrical shell with an eliptical-dome top called the bonnet. The shell is composed of a series of stacked rings that are all 4 ft in diameter but of various heights. Combinations of these rings are bolted together so that the height of the test chamber can be varied. The bonnet houses two firing tubes as well as baffles that aid in distributing the pressure generated by detonating explosives in the

firing tubes. The pressures generated over the soil surface are uniform to within 8 to 10 percent.

Three bases (Figure 2) are available for use. There are two rigid bases and an "infinite" bottom. The infinite bottom is a steel-lined hole, 9.5 ft deep, through the base slab.

200-Kip Dynamic Loader

The 200-Kip Loader (Figure 3) is an open-loop, hydraulically actuated, piston-type testing device capable of applying a concentrated load in short times over a maximum stroke of 4 in. The device can apply peak loads varying from 20,000 to 200,000 lb in either tension or compression and has applied loads in compression in excess of 200,000 lb. The rise-time characteristics of the applied load are a function of many variables, including piston location, magnitude of load, stiffness of the test specimen, and characteristics of the control valve. A minimum rise time of 1.3 msec for a load in excess of 200,000 lb with approximately 1/4-in. movement of the loading ram has been obtained during tests on very stiff, steel beams.

500-Kip Loader

The 500-Kip Loader is a closed-loop, servo-controlled, hydraulically actuated, piston-type system. The maximum travel of the piston is 18 in. in tension or compression with provisions to limit travel to 4 or 8 in. for compression loading. The device can be operated in several modes, i.e. by position control, by load-rate control, or by an arbitrary-function generator. Loads of 500 kips applied in 80 msec have been applied.

Dynamically Loaded Concrete Slabs

Background

The U. S. Army Corps of Engineers, in cooperation with the Office of Civil Defense, recently completed an extensive program concerned with locating and marking suitable areas in existing buildings as fallout shelters. These shelters afford varying degrees of protection from gamma radiation (fallout) and also would provide some protection from low-overpressure blast effects of nuclear and conventional explosions. However, little information is available that would enable engineers to predict the behavior and ultimate strength of existing conventional structures subjected to dynamic loads produced by the detonation of an explosive. In addition, little is known concerning the magnitude of the airblast overpressures required to collapse roofs, walls, floor slabs, and frame members in the structures.

Objective and scope

The objective of the study[2] at the WES was to investigate the performance and determine the dynamic ultimate strength of simply supported, rectangular, reinforced concrete slabs subjected to airblast overpressures below 25 psi. The structures tested in this study were square, simply supported, two-way reinforced concrete slabs with clear-span dimensions of 7 ft 6 in. and a thickness of 2-5/8 in. A total of four static and seventeen dynamic tests were conducted. The geometry and materials used were the same for all slabs tested; however, three different percentages of steel-reinforcement ratios were used. The slabs were subjected to uniformly distributed static loads to

approximately 12 psi, and dynamic airblast overpressures ranging from 7.3 to 13.2 psi. Repeated dynamic tests were conducted on two slabs.

The slabs were instrumented to record the strains on the concrete surfaces and steel reinforcement, deflected shape of the slabs, and pressure-time history of the loading. Acceleration measurements were made for the slabs and support structure that were loaded dynamically Velocity measurements were made for a few slabs so that deflections determined from singly integrated velocity records could be compared with deflections determined from double integrated acceleration records and direct deflection measurements.

Test procedures

The dynamic tests were conducted in the LBLG facility. The reaction structure used to support a test slab is shown in Figure 4. The reaction structure for the static tests was similar in principle to the one shown in Figure 4 except that a top lid over the structure was included as a reaction support for a flat, rubber, inflatable loading bag that was sandwiched between the test slab and the top lid.

The data for both static and dynamic tests were recorded electronically on three 36-channel oscillograph recorders. A magnetic-tape system was also used as a secondary or backup means of recording during dynamic tests. Pressure, strain, acceleration, velocity, and deflection were recorded during dynamic tests; only pressure, strain, and deflection were recorded during static tests. The deflection and strain measurements at one or more corresponding points were duplicated for all the static and dynamic tests. The geometry of the Series I test slab is shown in Figure 5. The geometries of the Series II and Series III test slabs were similar

except for small increases in percentage reinforcement. Each slab was numbered to identify it with a particular series, the type of test (static or dynamic), and the test number for a specific series. For example, ID2 is identified as the second (2) dynamic test (D) for a Series I slab.

Four slabs were filmed during dynamic testing using two fast-action cameras. The cameras were placed inside the reaction structure and both were preset at film speeds of approximately 2000 frames/sec. One camera had a 100-ft and the other a 400-ft film capacity. Eight long-duration flash bulbs provided the light during the filming.

Results and discussion

Static tests. The two Series I slabs, IS1 and IS2, failed at overpressures of 8.4 and 7.1 psi, respectively. Slab IIS1 failed at a pressure of 9.4 psi and slab IIIS1 failed at a pressure of 11.8 psi. The ultimate (collapse) load-carrying capacities of the slabs tested under static loads were approximately 1.42, 1.38, and 1.51 times the ultimate (flexural) load predicted by the yield-line analysis (conventional analysis) for the Series I, II, and III slabs, respectively. The collapse strength of the slabs was substantially affected by a membrane action which developed in the center quarter of the slab area.

The overall response and mode of failure of the four static tests were essentially the same. There were no continuous straight portions in the pressure-deflection curves, but the pressure increased steadily with deflection until the maximum or ultimate load was reached. General yielding of the reinforcement occurred at a midpoint deflection equal to approximately L/40, where L is the clear-span length.

The slabs failed in a flexural mode characterized by excessive yielding of the reinforcement and deflection.

Dynamic (airblast) tests. In Figures 6 and 7 are shown representative or typical conditions of several slabs after dynamic tests. All of the slabs tested were subjected to large overpressures. One slab collapsed appreciably; another slab, IID5 was subjected to a dynamic overpressure which resulted in a near collapse; and two slabs, ID3 (see Figures 6 and 7) and IID1, were severely damaged. Permanent inelastic deflections were incurred by all the test slabs.

A typical impulse-time curve is shown in Figure 8. Since the impulse-time curve was triangular in shape, it can be inferred that the pressure-time curve is essentially a step pulse. The pressure shown in the figure was determined by numerically differentiating the impulse curve.

Typical vertical deflection-time curves are shown in Figure 9 for various locations on slab IIID2. From such plots it was possible to determine the transient deflected shape of the slabs. Shown in Figures 10 and 11 are the recorded accelerations of the midpoint and quarter points of slab IIID2 along with velocity-time and deflection-time plots determined by performing, respectively, a single and double integration of the acceleration record. Also superimposed on the deflection curve as a dashed line are the appropriate deflection histories shown in Figure 9 for the direct deflection measurements. It is interesting to note the excellent agreement in the two deflection curves.

The results indicate that several factors influenced the dynamic

and permanent (residual) deflections. The most important were the magnitude of the surface overpressure and the percentage of slab reinforcement, the only two parameters purposely varied in the tests. The curves in Figure 12 indicate that the magnitude of the permanent midpoint deflections of the slabs increased exponentially with the magnitude of the surface overpressure, whereas the surface overpressure level required to induce equal permanent deflections varied proportionally with the percentage of slab reinforcement. The dynamic ultimate strengths of the slabs as determined from the curves in Figure 12 were approximately 11, 13, and 15 psi for Series I, II, and III, respectively.

The airblast loads required to cause collapse of the slabs were found to be approximately 1.43, 1.38, and 1.27 times the uniformly distributed static loads required to cause collapse for the Series I, II, and III slabs, respectively. As in the static tests, a membrane action developed in the slabs subjected to airblast loads.

Conclusions

The dynamic energy-absorption capacity of the simply supported slabs was as much as 35 percent greater than the static-energy absorption capacity. Strain rates of the reinforcing steel as high as 1 in./in./sec were observed in the tests, and only moderate damage was incurred by the slab. The deflections of the slabs determined from integration of the acceleration records were in good agreement with the deflections determined by direct measurements.

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2. DENTON, D. R. A Dynamic Ultimate Strength Study of Simply Supported Two-Way Reinforced Concrete Slabs. U. S. Army Engineer Waterways Experiment Station, CE. (In preparation.)

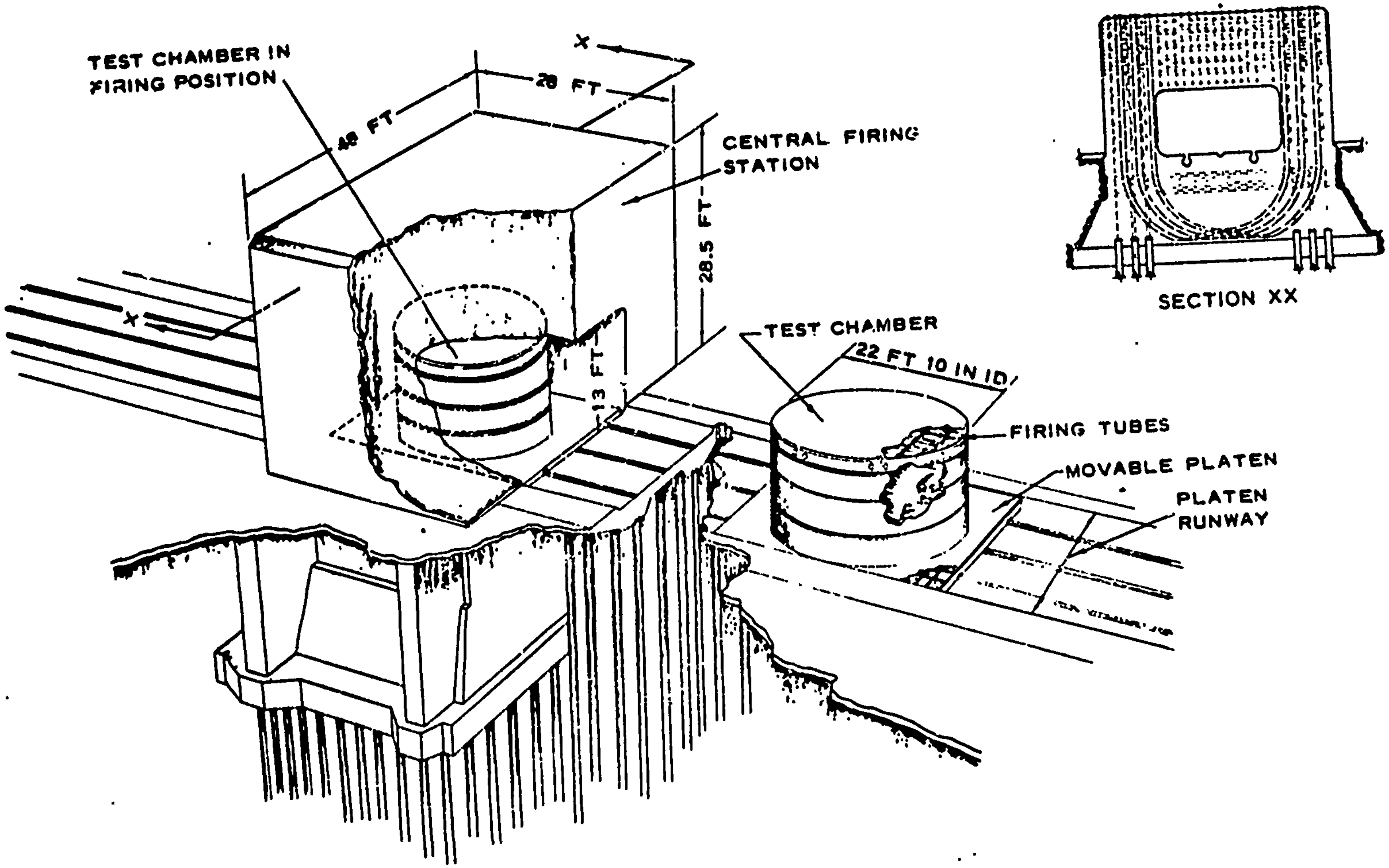


Figure 1. Large Blast Load Generator.

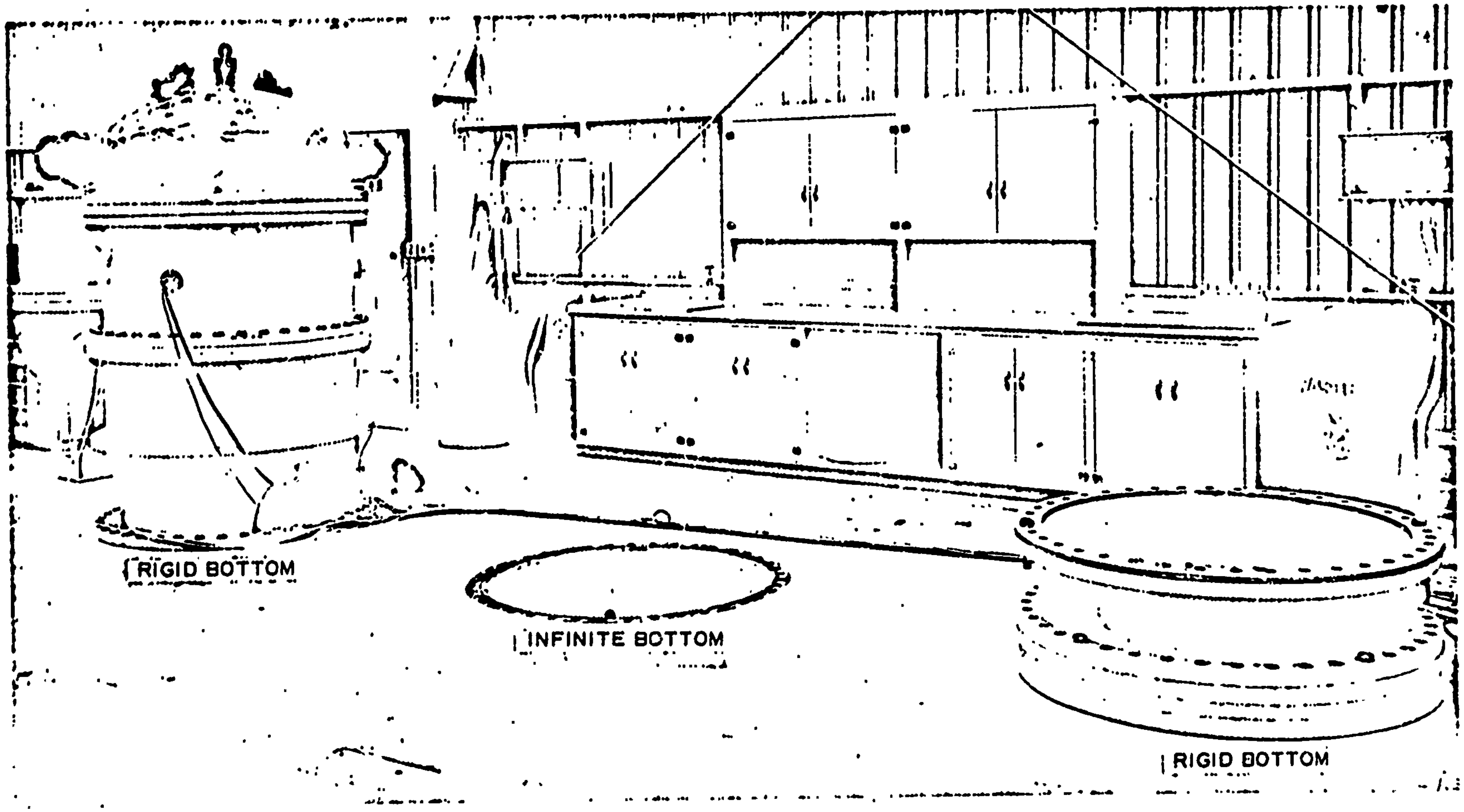


Figure 2. Small Blast Load Generator.

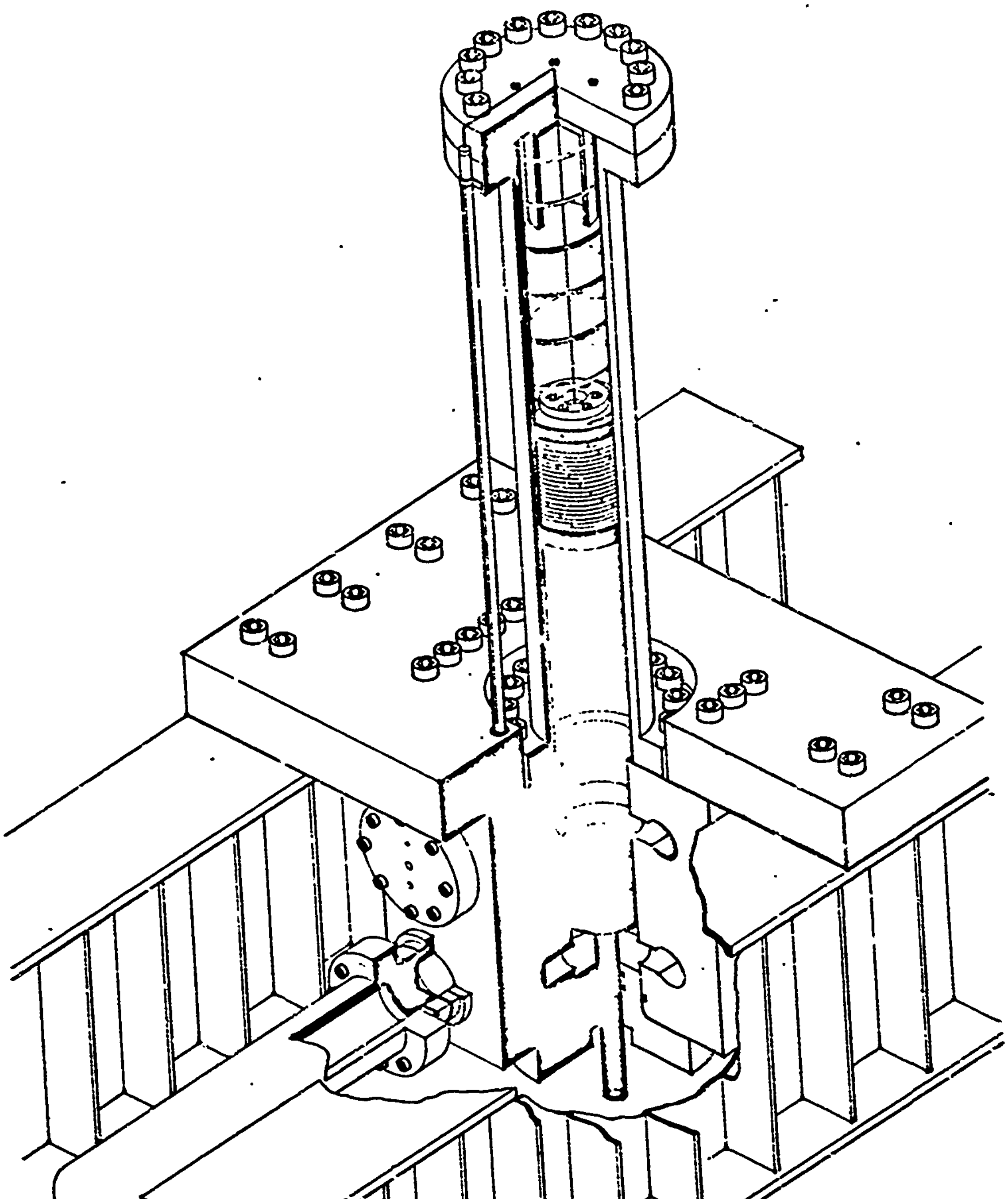


Figure 3. 200-Kip Dynamic Loader.

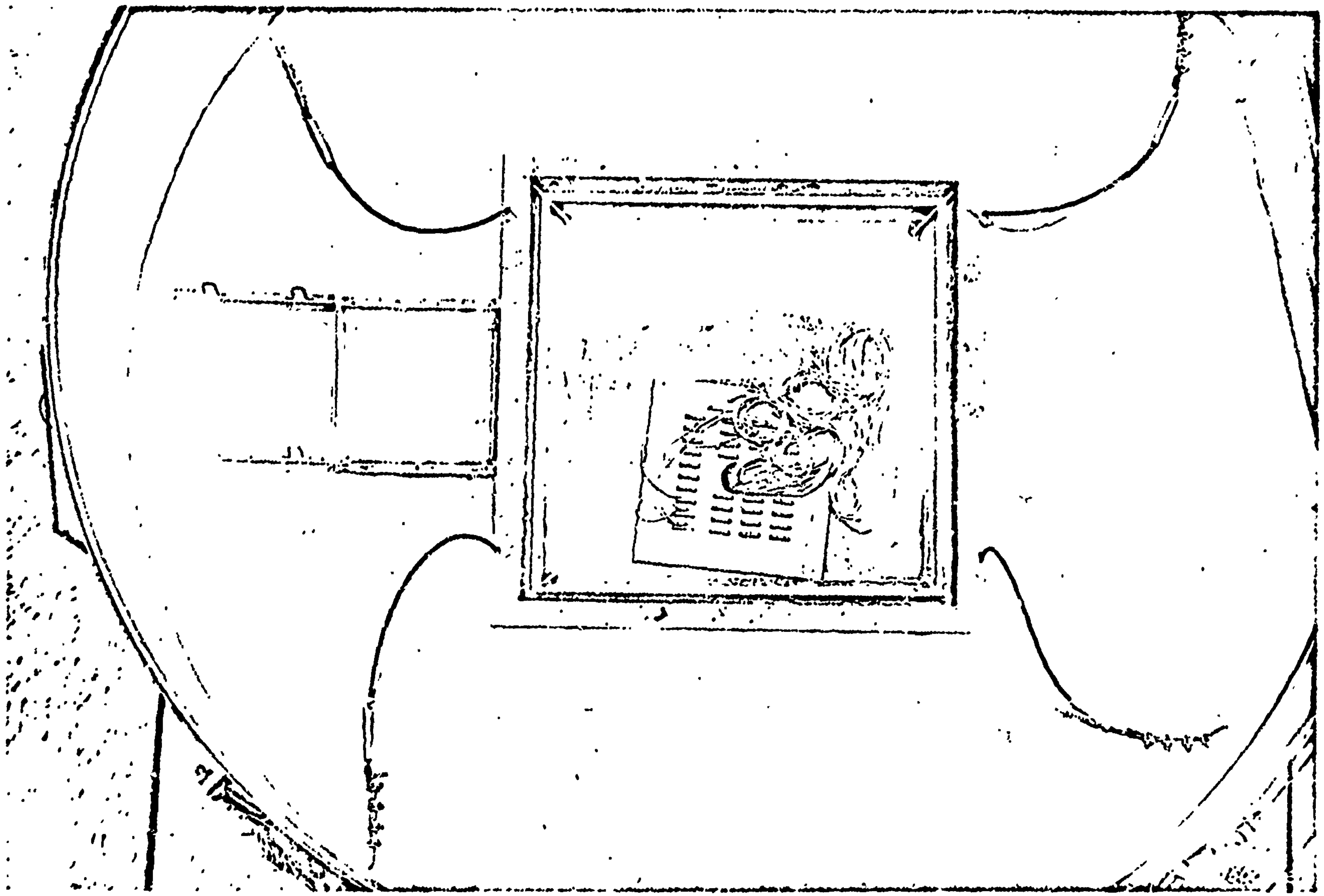
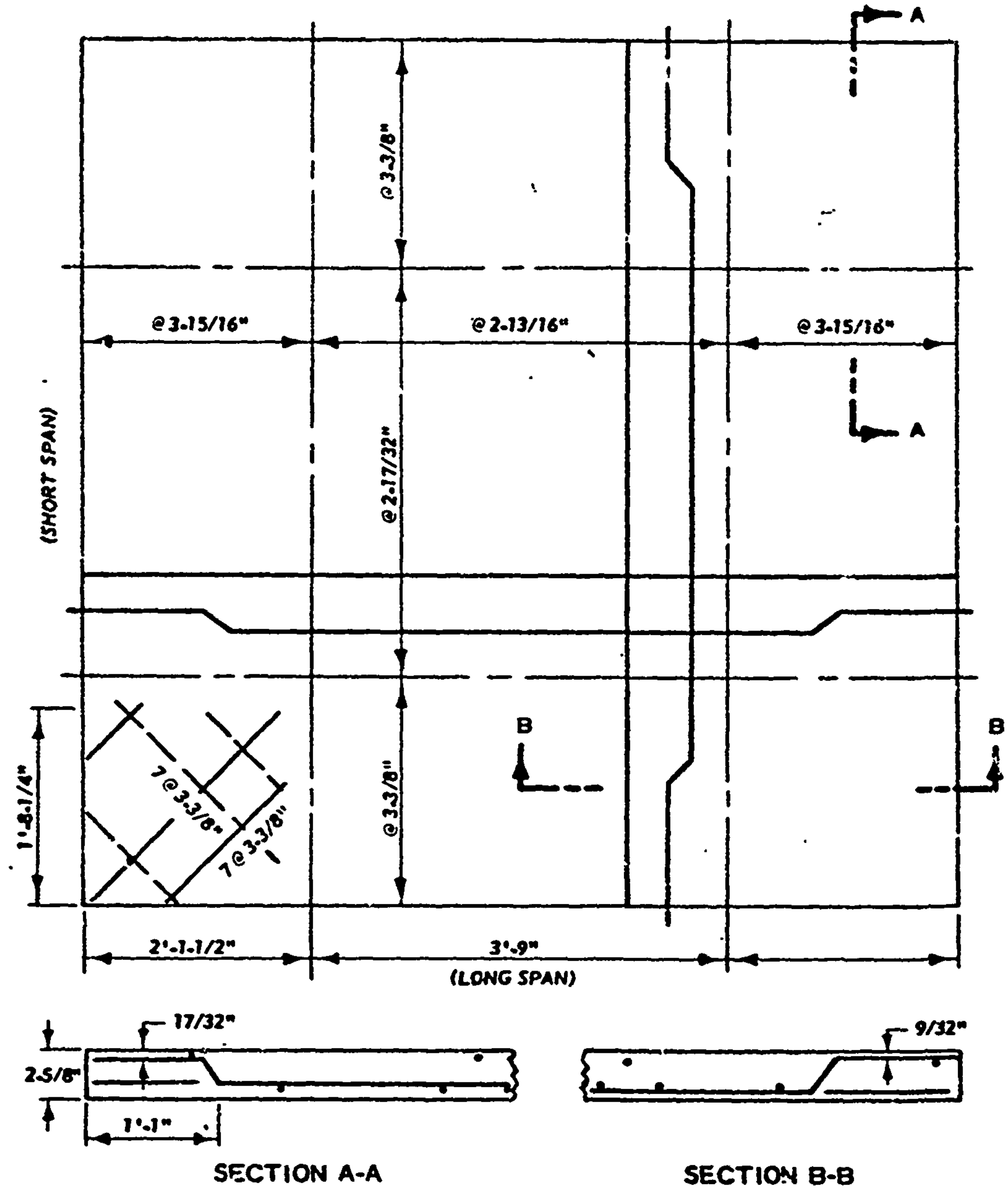


Figure 4. Dynamic reaction structure in test chamber.



NOTES:
1. ALL REINFORCEMENT IS #2, DEFORMED BARS.
2. ALTERNATE BARS ARE BENT UP.

Figure 5. Working drawings for Series I slabs.

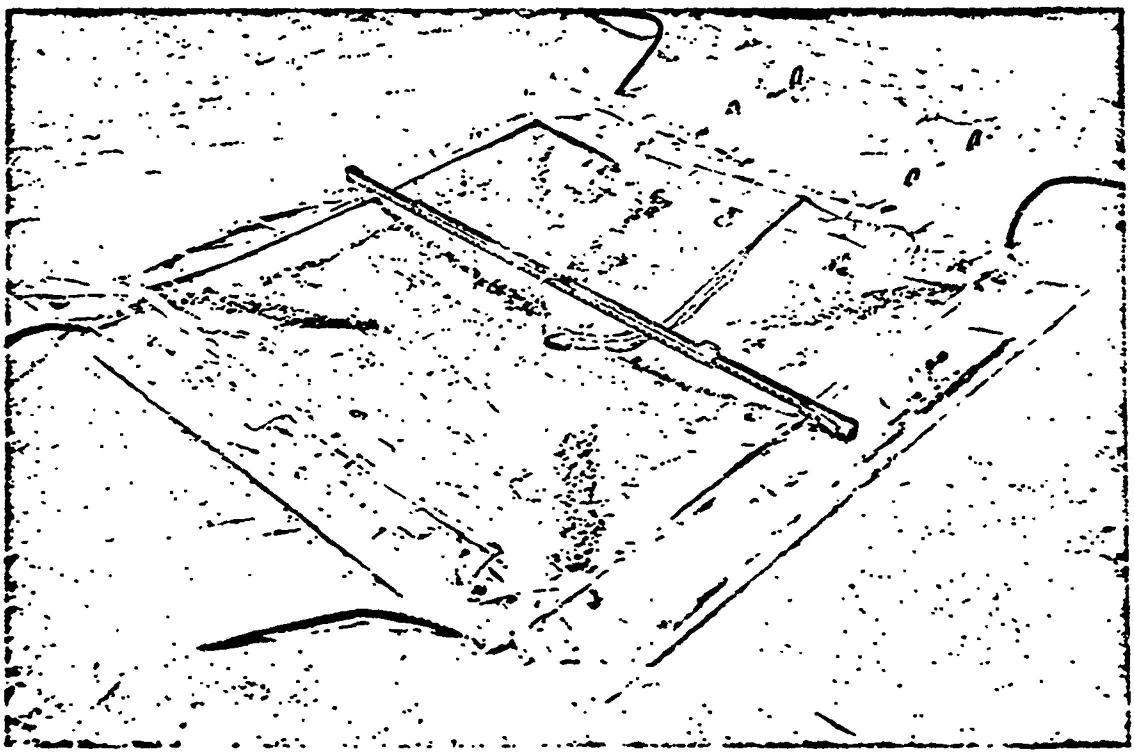


Figure 6. Compression surface (ID3), 9.7-psi overpressure.

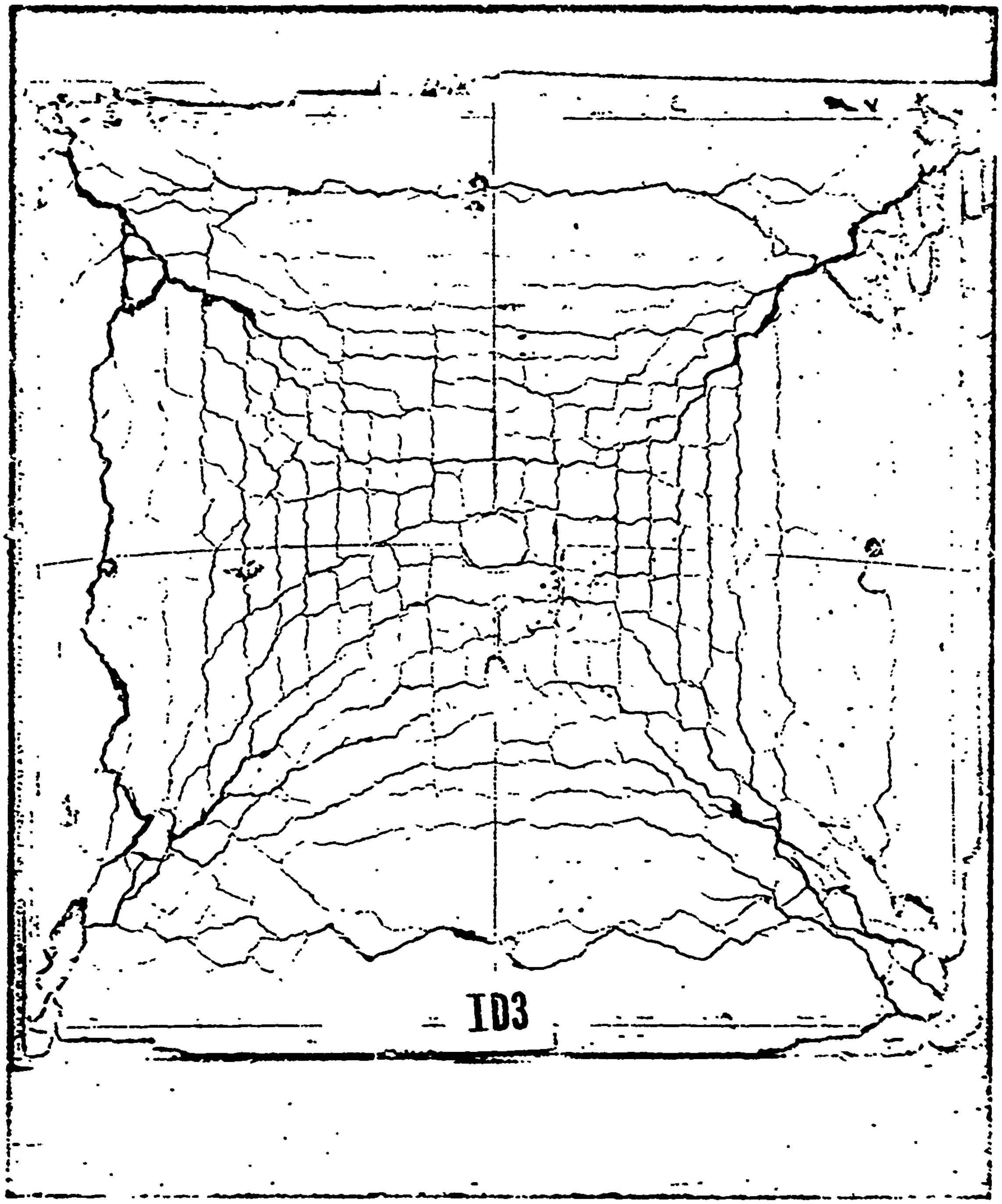


Figure 7. Tension surface (ID3), 9.7-psi overpressure.

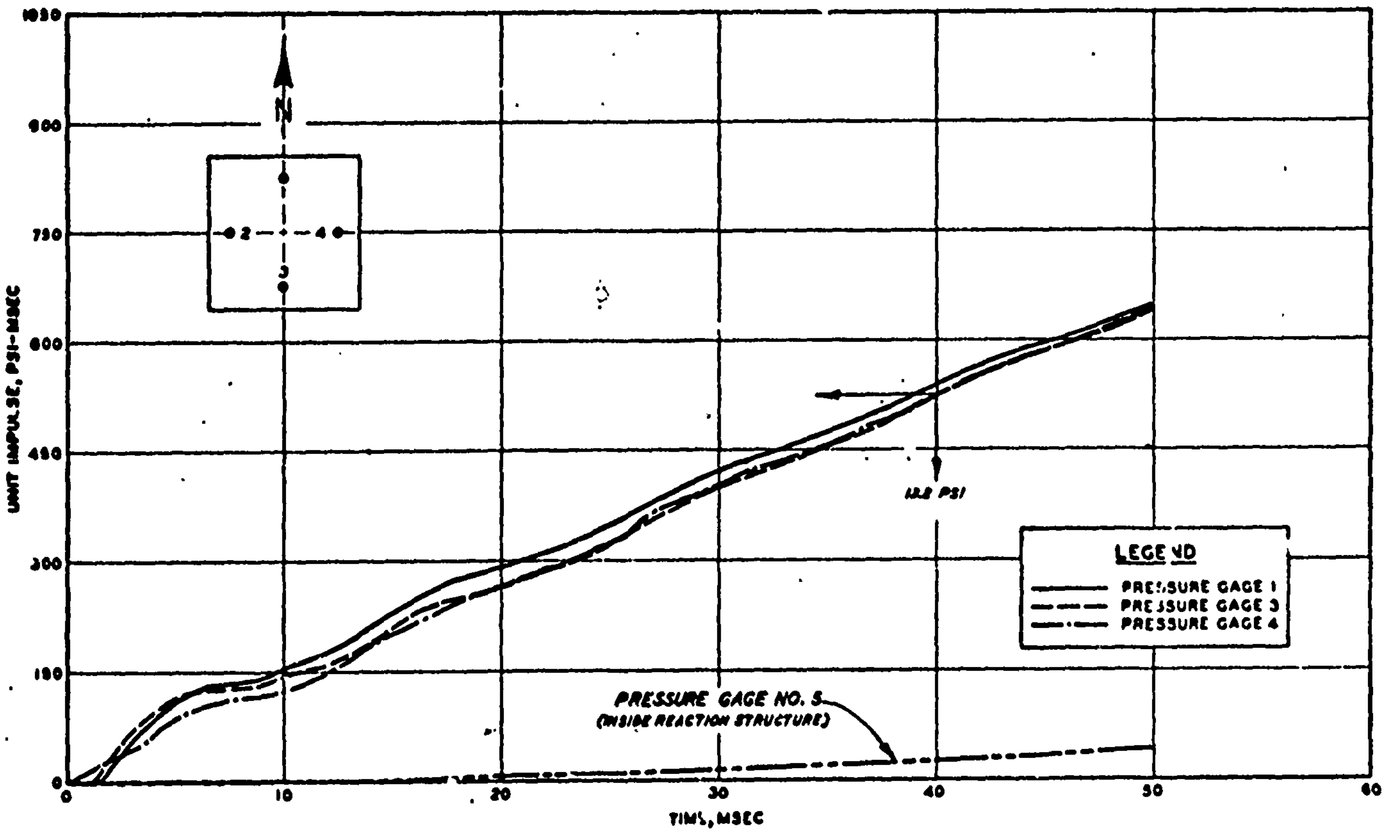


Figure 8. Impulse-time curves for slab IIID1.

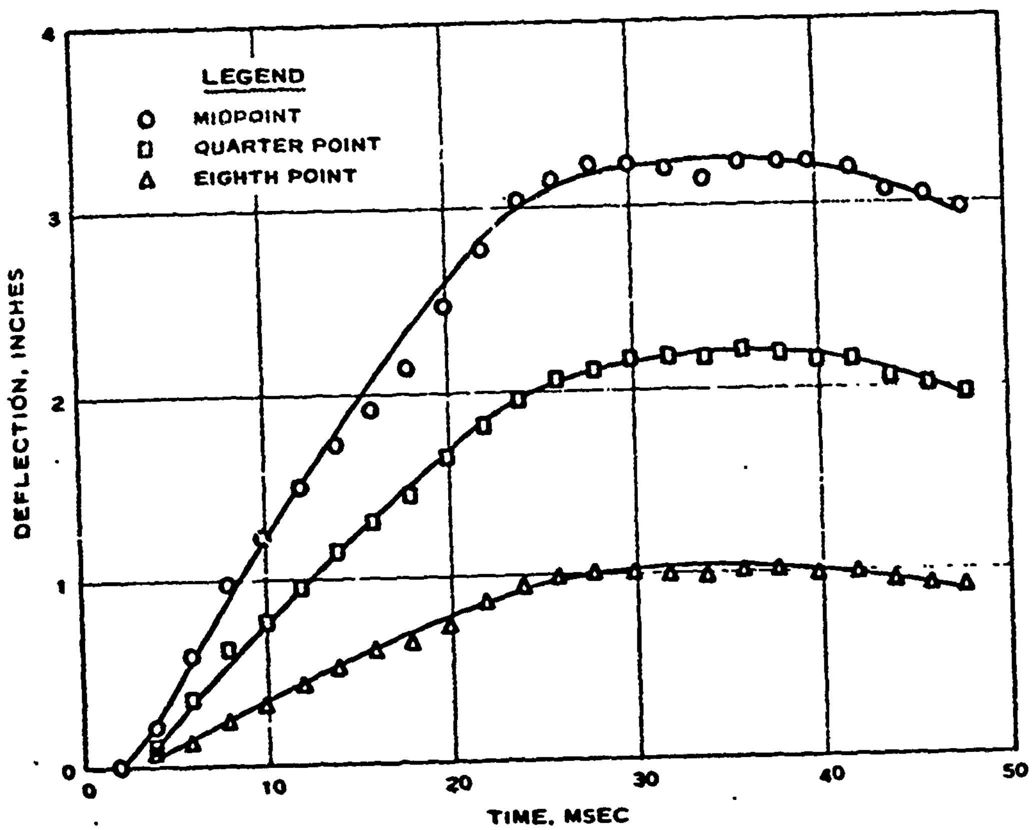


Figure 9. Dynamic deflections for slab IIID2, first test (8.5-psi overpressure).

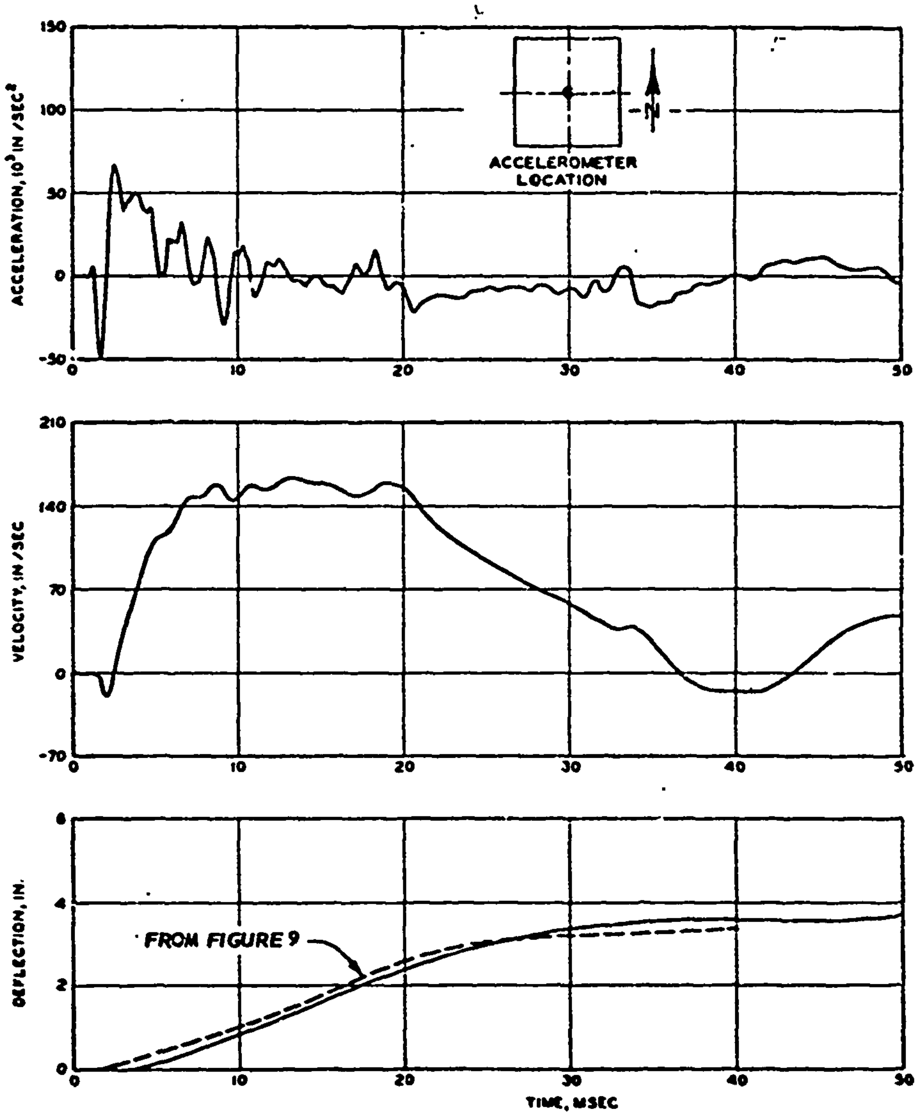


Figure 10. Acceleration-, velocity-, deflection-time curves for midpoint of slab IIID2, first test (8.5-psi overpressure).

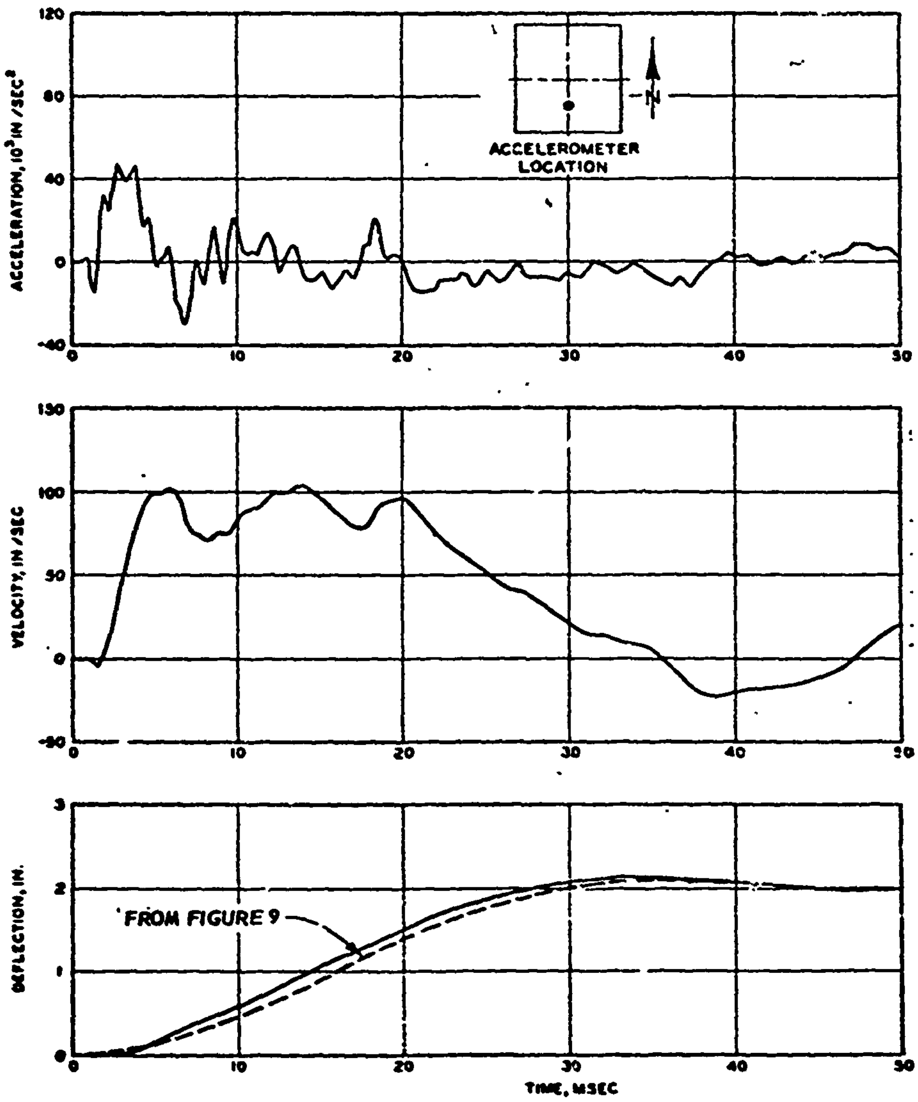


Figure 11. Acceleration-, velocity-, deflection-time curves for quarter point of slab IIID2, first test (8.5-psi overpressure).

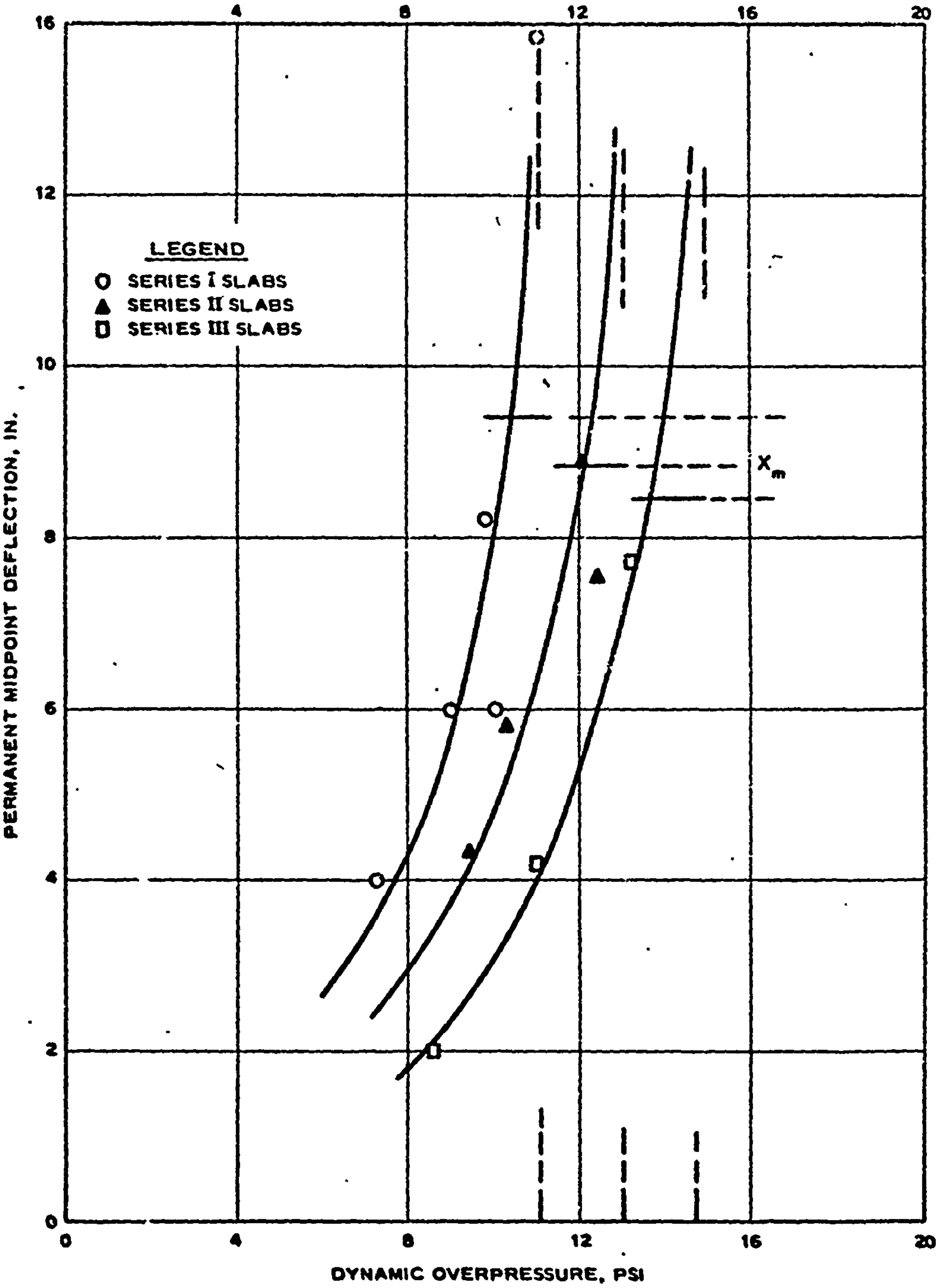


Figure 12. Permanent midpoint deflections versus dynamic overpressure.